Search for doubly-charged Higgs bossons in like-sing dilepton final states at $\sqrt{s} = 7\ TeV$ with the ATLAS detector

Using a data sample with an integrated luminosity of $4.7 \pm 0.2\ fb^{-1}$ of *pp* collisions

Doubly charged Higgs model

❖ SU(2) group:

❖ Singlet: $\Phi = H^{++}$, $(T = 0, T_3 = 0, Y = 2)$

❖ Doublet: $\Phi = \begin{pmatrix} H^{++} \\ H^{+} \end{pmatrix}$, $(T = 1/2, T_3 = 1/2, Y = 3/2)$

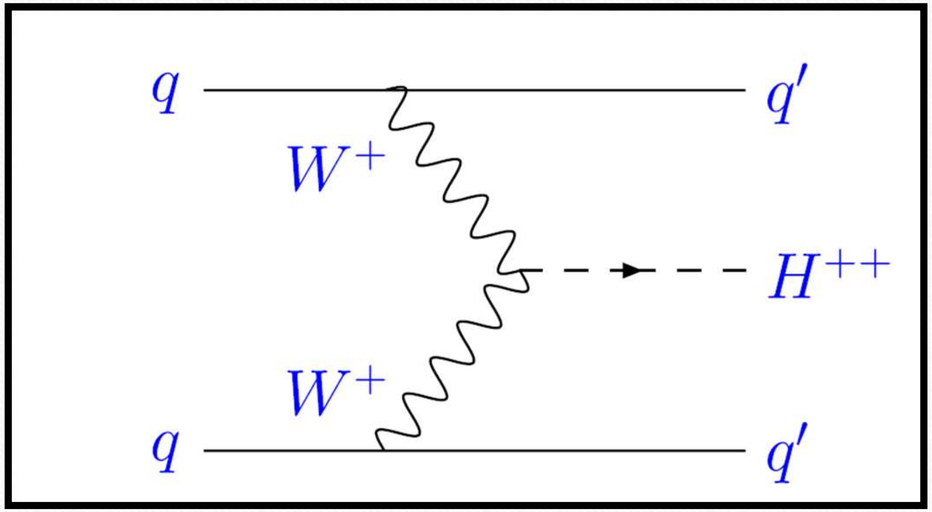
❖ Triplet: $\Phi = \begin{pmatrix} H^{+}/\sqrt{2} & H^{++} \\ H^{0} & -H^{+}/\sqrt{2} \end{pmatrix}$, $(T = 1, T_3 = 1, Y = 1)$

Left-Right symmetric models

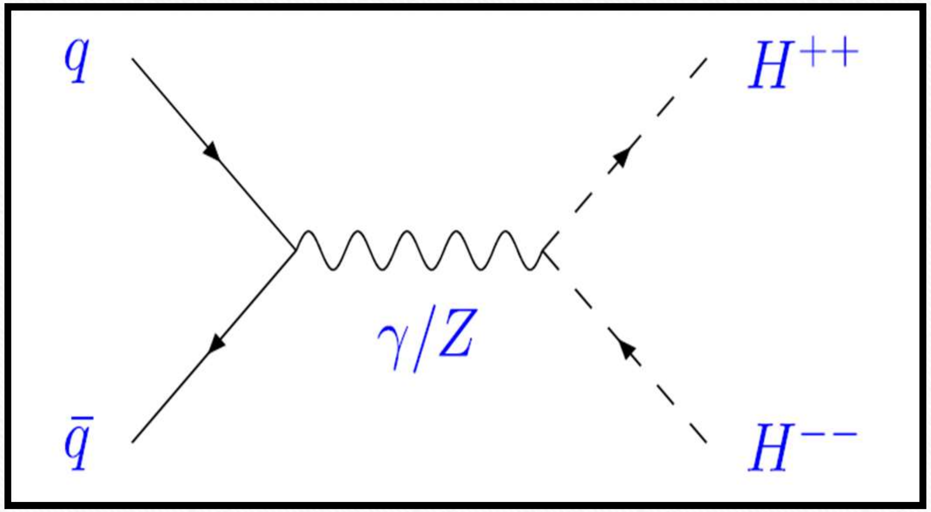
- Doubly-charged Higgs bosons can couple to left-handed or right-handed fermion
- Denoted as $H_L^{\pm\pm}$ and $H_R^{\pm\pm}$ (Y=2)
- $\sigma(H_L^{++}\ H_L^{--}) > 2.5\ \sigma(H_R^{++}\ H_R^{--})$
- Good way to explain the origin of neutrino masses: “Type II Seesaw” mechanism

Two mainly production mechanism

Vector Boson Fusion process (VBF)

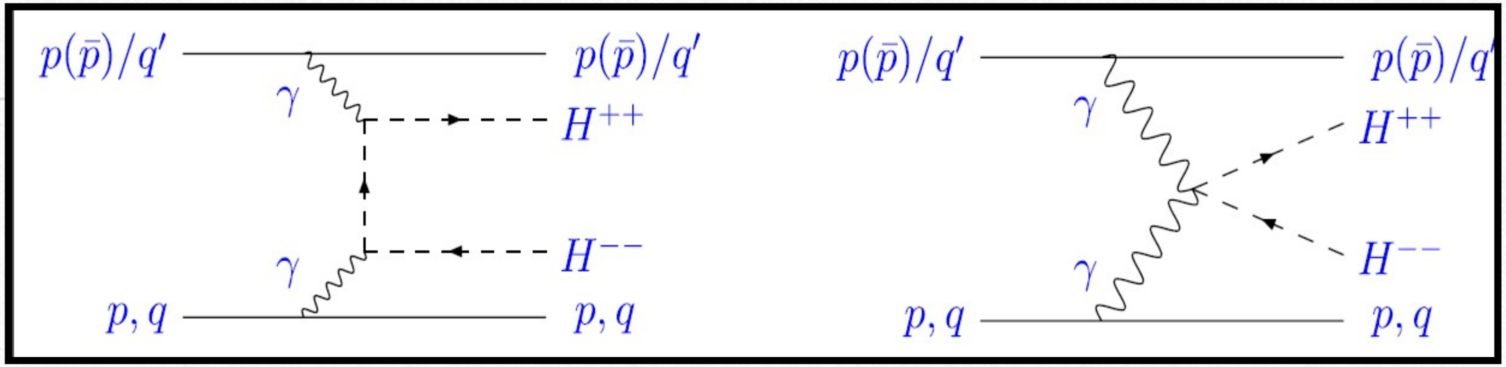


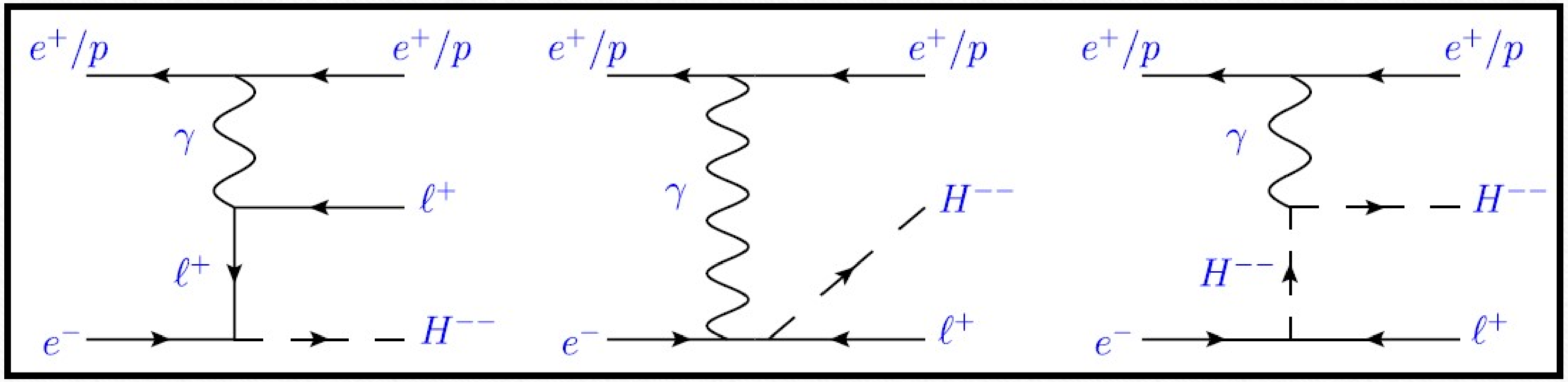
Drell-Yan pair production



Doubly charged Higgs boson production channels

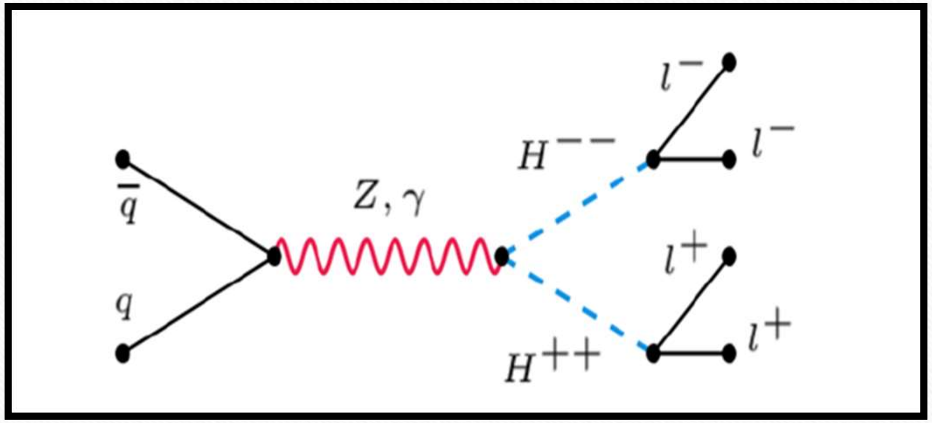
Two-photon fusion process





Single production via h_{el} coupling

Drell-Yan Pair production



$$\Gamma(H^{\pm\pm} \to l^{\pm} l'^{\pm}) = k \frac{h_{ll'}^2}{16\pi} m(H^{\pm\pm})$$

Prompt decays: $c\tau < 10\mu m$

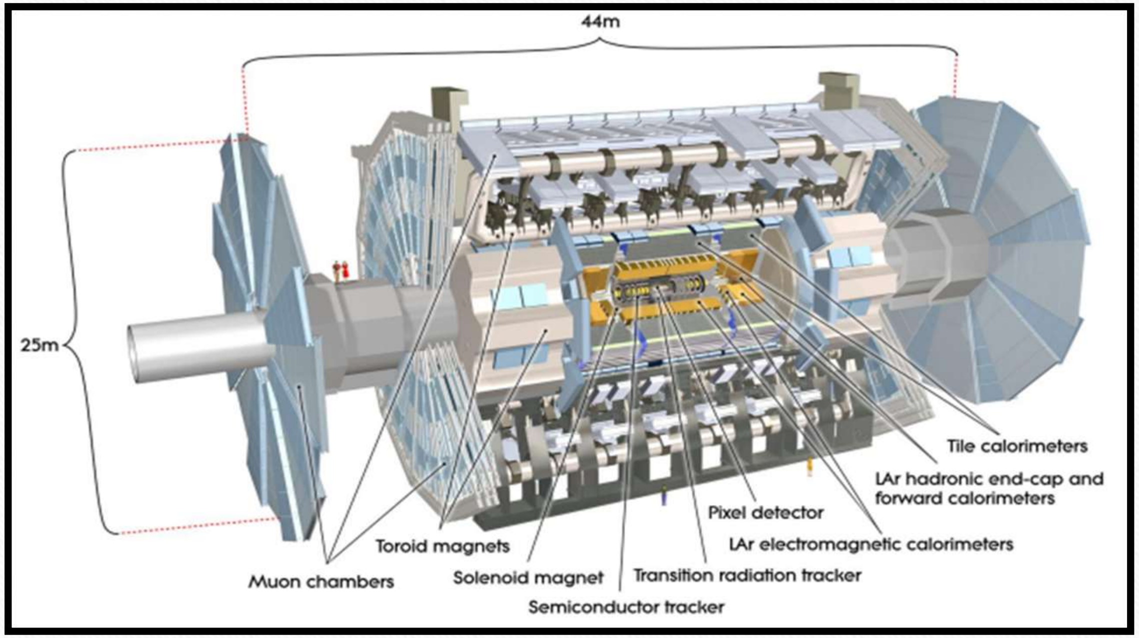
$$\underbrace{\begin{gathered} h_{ll'} > 3 \times 10^{-6} \\ m(H^{\pm\pm}) > 50GeV \end{gathered}}$$

Lepton identification and mass of $H^{\pm\pm}$

Final state	Mass limit of $H^{\pm\pm}$
$e^{\pm}e^{\pm}$	>382 GeV
$\mu^{\pm}\mu^{\pm}$	>391 GeV
$\mu^{\pm}e^{\pm}$	>395 GeV

Direct measurements calculated in LEP, HERA, Tevatron, and LHC colliders with BR 100% and CL 95%.

ATLAS detector



- ❖ Electron identified at the calorimeter and tracked in the inner detector (ID) using the *tight* (including *loose* and *medium*) criteria.

- ❖ Muons identified in the inner tracking system and muon detector.

Event selection

- For ee production, the range $70\text{GeV} < m(e^{\pm}e^{\pm}) < 110GeV$ is excluded due to large Background from Z events
- Tight criteria for electrons
- Electrons must have $|\eta| < 2.47$ (except $1.37 < |\eta| < 1.52$)
- Muons must have $|\eta| < 2.5$
- More than one lepton pair may be reconstructed per event

Trigger system

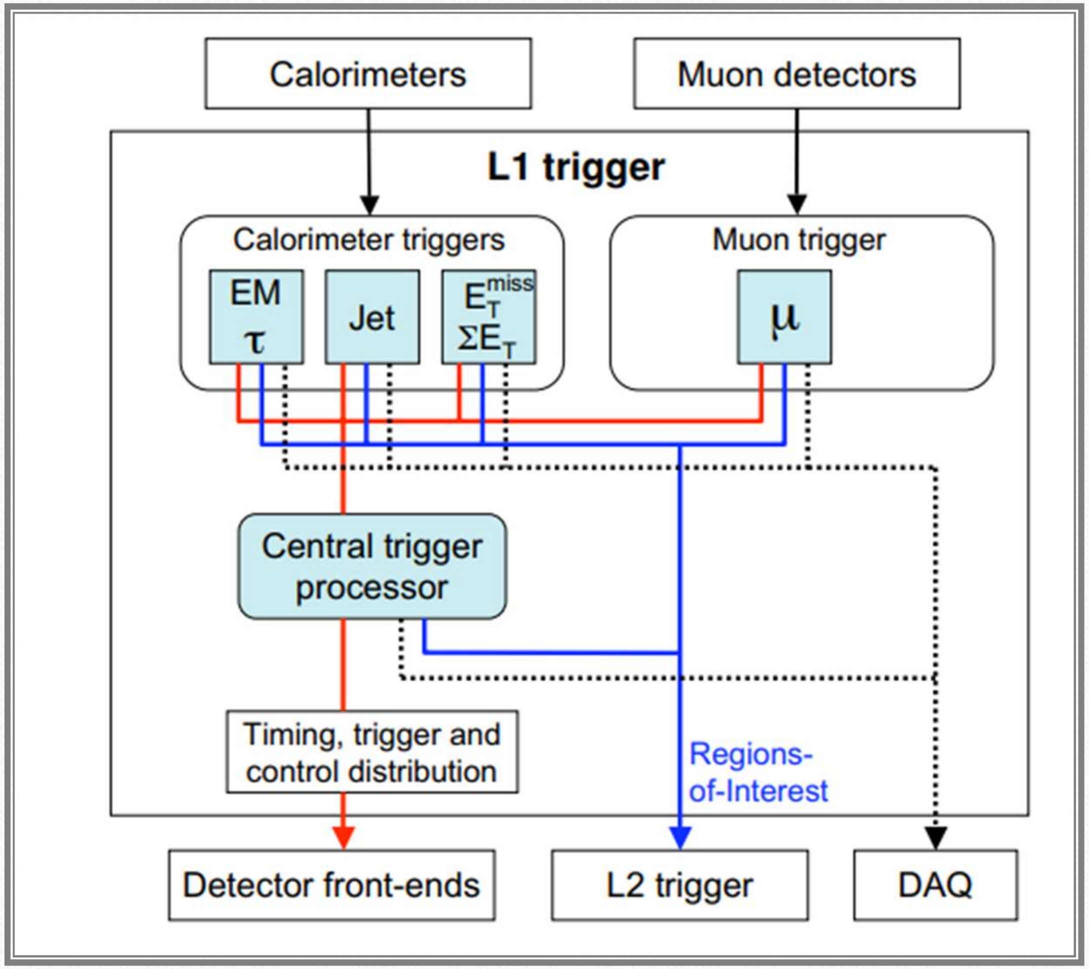
L1 trigger and HL trigger

$p_T > 20\ GeV$

Higher p_T is an electron:

$p_T > 25\ GeV$

For no efficiency loss of electrons with very high p_T , trigger with threshold of 45 GeV



Leptons

- Primary interaction vertex
- Isolation
- Separation of jets

Primary interaction vertex

❖ The ID tracks of electron and muon candidates are required to be consistent with originating from the primary interaction vertex

- $|d_0| < 1mm$ and $|d_0/\sigma(d_0)| < 3$
- Hit in the innermost pixel detector layer is required
- Also reduces background

Isolation

❖Electrons and muons must be well isolated:

- $\frac{p_T^{cone0.4}}{p_T(\mu)} < 0.06\ and\ E_T^{cone0.4} < 4GeV + 0.02p_T(\mu)$
- $\frac{p_T^{cone0.3}}{p_T(e)} < 0.1\ and\ E_T^{cone0.2} < 3GeV + 0.037(p_T(e) - 20GeV)$
- $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$

Separation of jets

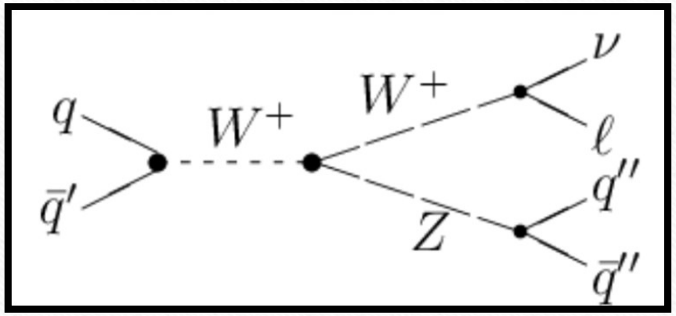
❖Well separated from jets to suppress leptons from hadronic decays

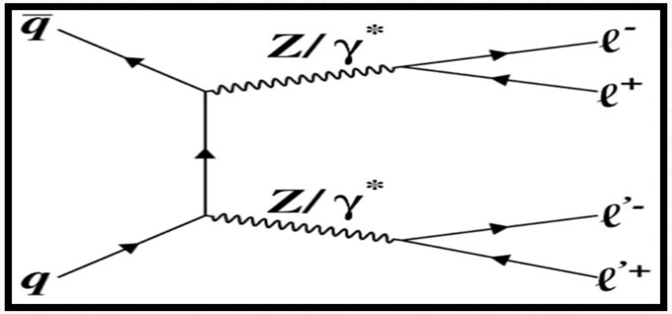
- Jet candidates reconstructed from topological clusters in the calorimeter
- Jets: p_T > 25GeV, $|\eta|$ < 2.8
- Leptons separeted by separated by $\Delta R > 0.4$ from any jet

SM Backgrounds

- Prompt sources
- Non-prompt sources
- Conversion sources

Prompt sources





- WZ production
- ZZ production

SHERPA

- Like sign WW production
- $t\bar{t}W$ production
- $t\bar{t}Z$ production

MADGRAPH and PYTHIA

Non-Prompt sources

- Determined directly from Data
- $f = \frac{N_S}{N_A}$, where N_A depends on the flavour of the lepton
- $f = f(p_T, \eta)$
- We study separately Muons and Electron production

Muons

- Semileptonic b and c-hadrons decays
- $\frac{p_T^{cone0.4}}{p_T(\mu)} < 1, |d_0/\sigma(d_0)| > 5$ and $|d_0| < 10mm$
- Muons with $|d_0/\sigma(d_0)| < 3$ are more isolated
- $f \approx 0.10 \ (p_T = 20\ GeV)$ and $f \approx 0.25 \ (p_T = 100\ GeV)$
- Systematic uncertainty in f about $\pm 37\%$ at low p_T and $\pm 100\%$ for $p_T > 100\ GeV$

Electrons

- Background from charged pions that shower earlier in the calorimeter and neutral pions decaying in two photons (one of them decays on $e^{+}e^{-}$)
- $|d_0/\sigma(d_0)| > 3$ (or fail the *medium* electron identification criteria).
- $f \approx 0.18 \ (E_T = 20\,GeV)$ and $f \approx 0.10 \ (E_T = 100\,GeV)$
- Systematic uncertainty in f about $\pm 10\%$ at low E_T and $\pm 100\%$ for $E_T > 300\,GeV$

Non-Prompt Background prediction

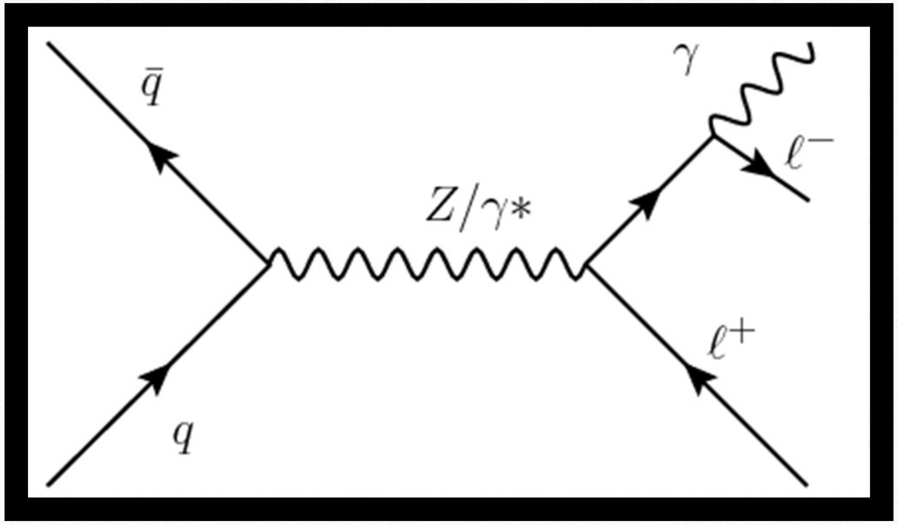
- Derived from f using dilepton pairs where one or both leptons are anti-selected but pass all other event selection criteria
- $\mathbf{N_{NP}} = \sum_{\mathbf{i=1}}^{\mathbf{N_{A+S}}} \mathbf{f(p_{T1}, \eta_1)} + \sum_{\mathbf{i=1}}^{\mathbf{N_{S+A}}} \mathbf{f(p_{T2}, \eta_2)} - \sum_{\mathbf{i=1}}^{\mathbf{N_{A+A}}} \mathbf{f(p_{T1}, \eta_1) f(p_{T2}, \eta_2)}$
- N_{A+S}, N_{S+A} and N_{A+A} substracted based con MC predictions

Conversion sources ($e^{\pm}e^{\pm}$)

- ❖ $W\gamma$ and $Z\gamma$ production

- ❖ Electron charge flip $Z, \gamma \rightarrow e^{+}e^{-}$
- ❖ $70\ GeV < m(e^{\pm}e^{\pm}) < 110 GeV$ excluded due to Z boson coupling

- ❖ MC simulation



Charge misidentification

- For muons this is negligible in the range of p_T found in the sample
- One electron reconstructed with wrong charge after radiating a photon
- Charge-flip overlap fraction $(23 \pm 3)\%$
- To avoid double counting, overlap $70\ GeV < m(e^{\pm}e^{\pm}) < 110GeV$ removed

Control regions

- Prompt leptons background tested in a sample requiring two leptons of opposite charge, dominated by $Z/\gamma*$ in all final states
- Non-Prompt background tested inverting the isolation criteria
- Agree with the background prediction

Systematic uncertainties

- ❖ $50\ GeV < m(H^{\pm\pm}) < 1000\ GeV$
- ❖ Detector resolution → 1.2-1.8% for e, 2-10% for μ
- ❖ Lepton identification →$\pm(3-4)\%$
- ❖ Trigger efficiencies → $< 3.5\%$
- ❖ $\mathcal{L}$ → $\pm 3.9\%$
- ❖ $A \times \epsilon$ → 27-50% depending on $m(H^{\pm\pm})$

Systematic uncertainties

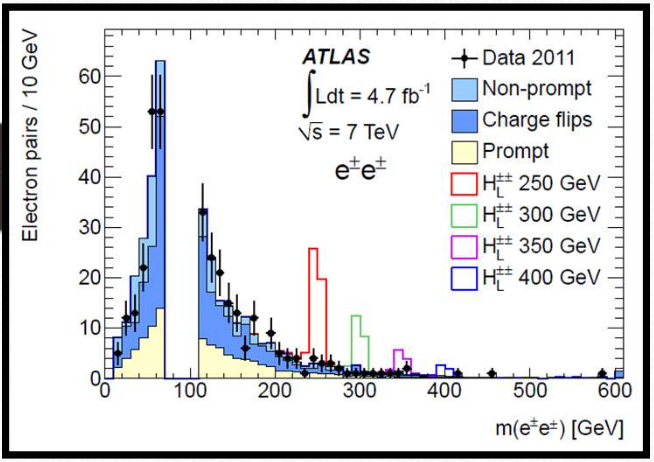
- ❖ WZ and ZZ cross section → $\pm 12\%$
- ❖ $t\bar{t}W$, $t\bar{t}Z$ and $W^{\pm}W^{\pm}$ → $\pm 50\%$
- ❖ Z/γ∗→ $\pm 7\%$
- ❖ $W^{\mp}W^{\pm}$ → $\pm 12\%$
- ❖ Non-prompt leptons → >28% depending on the flavor and $m(l^{\pm}l^{\pm})$
- ❖ Non-prompt and conversion sources at low masses → $\pm 40\%$

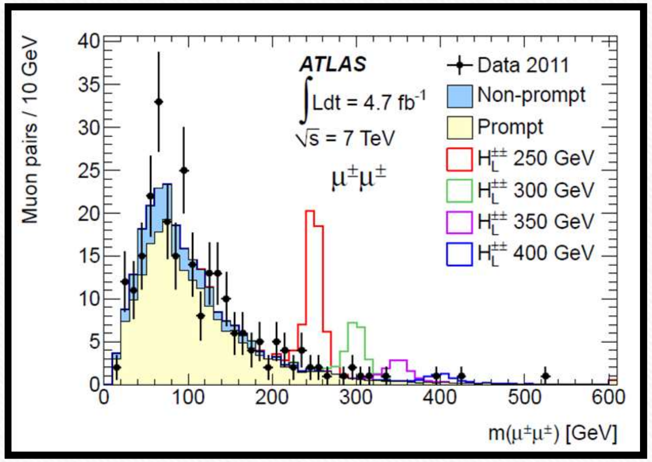
Data

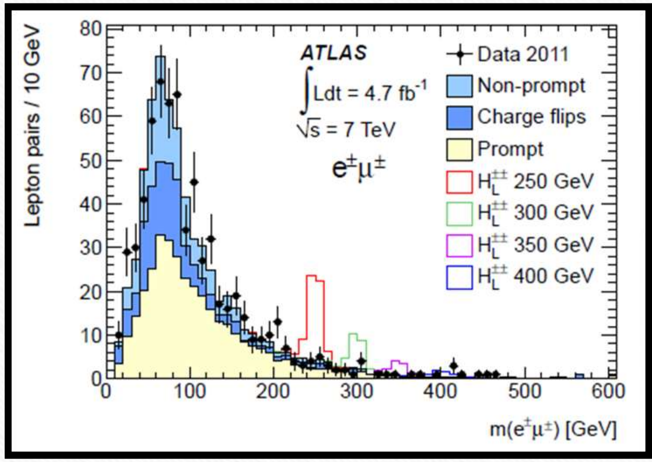
Sample	Number of electron pairs with $m(e^{\pm}e^{\pm})$				
	> 15 GeV	> 100 GeV	> 200 GeV	> 300 GeV	> 400 GeV
Prompt	101 ± 13	56.3 ± 7.2	14.8 ± 2.0	4.3 ± 0.7	1.4 ± 0.3
Non-prompt	75 ± 21	28.8 ± 8.6	5.8 ± 2.5	$0.5^{+0.8}_{-0.5}$	$0.0^{+0.2}_{-0.0}$
Charge flips and conversions	170 ± 33	91 ± 16	22.1 ± 4.4	8.0 ± 1.7	3.4 ± 0.8
Sum of backgrounds	346 ± 44	176 ± 21	42.8 ± 5.7	12.8 ± 2.1	4.8 ± 0.9
Data	329	171	38	10	3
	Number of muon pairs with $m(\mu^{\pm}\mu^{\pm})$				
	> 15 GeV	> 100 GeV	> 200 GeV	> 300 GeV	> 400 GeV
Prompt	205 ± 26	90 ± 11	21.8 ± 2.8	5.8 ± 0.9	2.2 ± 0.4
Non-prompt	42 ± 14	12.1 ± 4.6	1.0 ± 0.6	$0.0^{+0.3}_{-0.0}$	$0.0^{+0.3}_{-0.0}$
Charge flips	$0.0^{+4.9}_{-0.0}$	$0.0^{+2.5}_{-0.0}$	$0.0^{+1.8}_{-0.0}$	$0.0^{+1.7}_{-0.0}$	$0.0^{+1.7}_{-0.0}$
Sum of backgrounds	247^{+30}_{-29}	102 ± 12	$22.8^{+3.4}_{-2.9}$	$5.8^{+1.9}_{-0.9}$	$2.2^{+1.7}_{-0.4}$
Data	264	110	29	6	2
	Number of lepton pairs with $m(e^{\pm}\mu^{\pm})$				
	> 15 GeV	> 100 GeV	> 200 GeV	> 300 GeV	> 400 GeV
Prompt	346 ± 43	157 ± 20	36.6 ± 4.7	10.8 ± 1.5	3.9 ± 0.6
Non-prompt	151 ± 47	45 ± 13	9.2 ± 4.1	2.6 ± 1.1	1.0 ± 0.6
Charge flips and conversions	142 ± 28	33 ± 7	10.5 ± 2.8	2.9 ± 1.2	2.2 ± 1.1
Sum of backgrounds	639 ± 71	235 ± 25	56.4 ± 7.0	16.3 ± 2.3	7.0 ± 1.4
Data	658	259	61	17	7

Sample	Number of lepton pairs with $m(\ell^{\pm}\ell^{\pm})$				
	> 15 GeV	> 100 GeV	> 200 GeV	> 300 GeV	> 400 GeV
	e^+e^+ pairs				
Sum of backgrounds	208 ± 28	112 ± 14	28.6 ± 4.0	8.5 ± 1.4	3.3 ± 0.7
Data	183	93	26	6	1
	e^-e^- pairs				
Sum of backgrounds	138 ± 21	63.3 ± 8.5	14.2 ± 2.3	4.4 ± 0.8	$1.54^{+0.4}_{-0.3}$
Data	146	78	12	4	2
	$\mu^+\mu^+$ pairs				
Sum of backgrounds	147 ± 17	$63.7^{+7.7}_{-7.6}$	$14.5^{+2.1}_{-1.9}$	$4.1^{+1.1}_{-0.6}$	$1.6^{+0.9}_{-0.3}$
Data	144	60	16	4	2
	$\mu^-\mu^-$ pairs				
Sum of backgrounds	100 ± 12	$38.4^{+5.0}_{-4.8}$	$8.3^{+1.5}_{-1.2}$	$1.7^{+0.9}_{-0.3}$	$0.6^{+0.9}_{-0.1}$
Data	120	50	13	2	0
	$e^+\mu^+$ pairs				
Sum of backgrounds	381 ± 42	142 ± 15	33.8 ± 5.3	9.8 ± 1.5	4.2 ± 0.9
Data	375	149	39	9	4
	$e^-\mu^-$ pairs				
Sum of backgrounds	259 ± 31	93 ± 10	22.6 ± 3.0	6.5 ± 1.3	2.9 ± 1.0
Data	283	110	22	8	3

Data

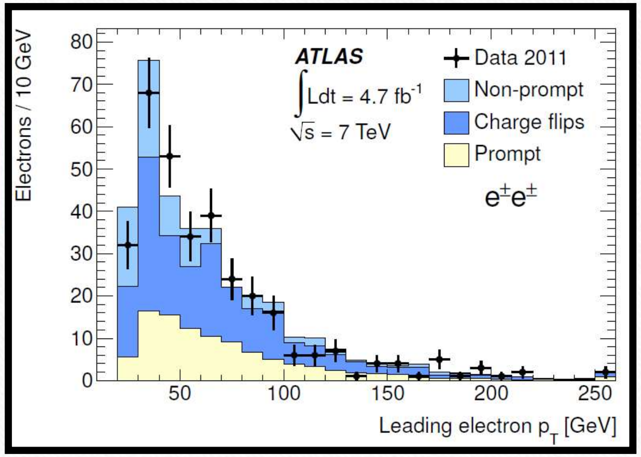




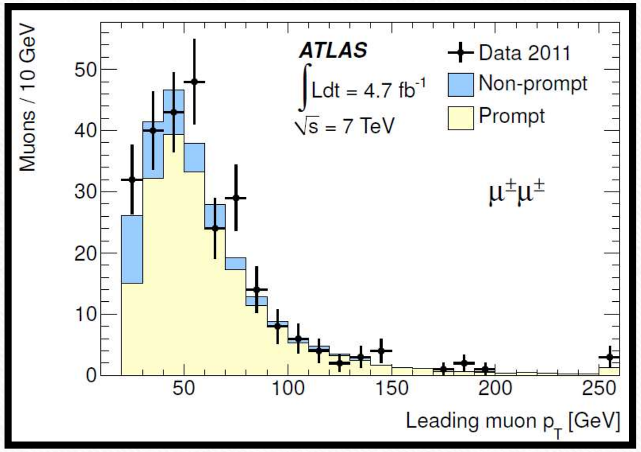


- ❖ Four hypothetical $H^{\pm\pm}$ signals shown
- ❖ Good agreement with the background expectation for all three channels
- ❖ No clear peak structure

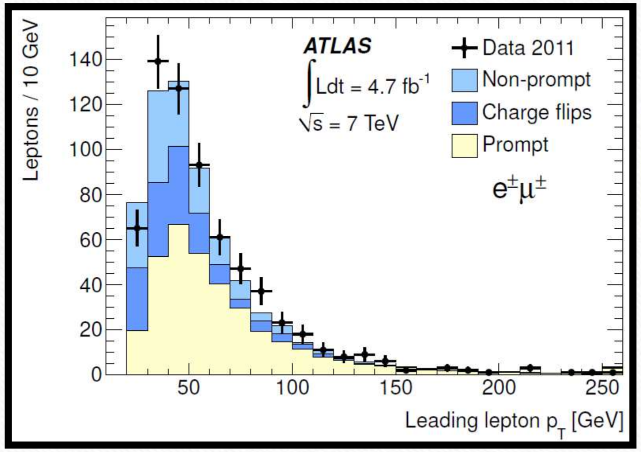
Data



ATLAS
∫Ldt = 4.7 fb⁻¹
√s = 7 TeV
Data 2011
Non-prompt
Charge flips
Prompt
e±e±
Electrons / 10 GeV
Leading electron p_T [GeV]



ATLAS
∫Ldt = 4.7 fb⁻¹
√s = 7 TeV
Data 2011
Non-prompt
Prompt
μ±μ±
Muons / 10 GeV
Leading muon p_T [GeV]

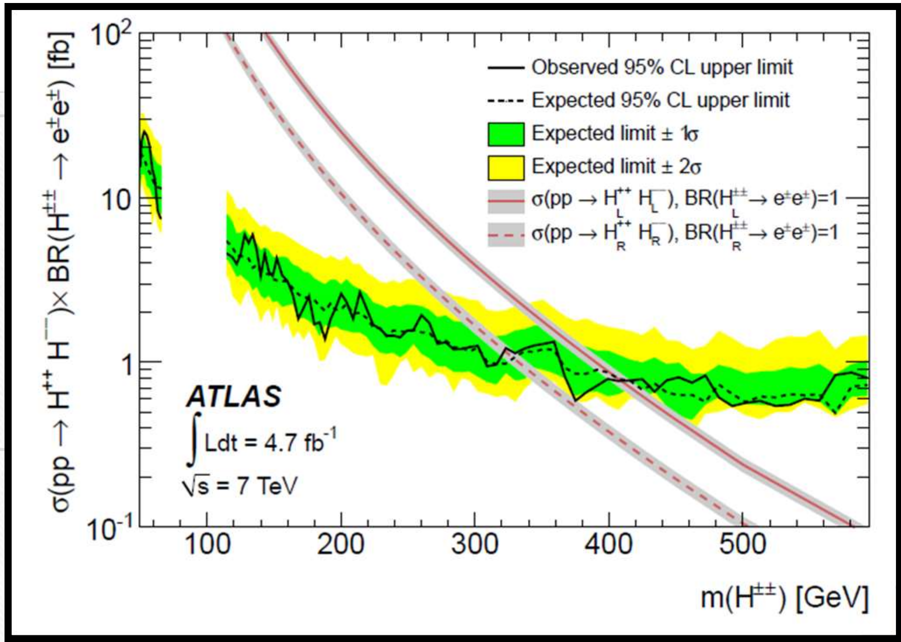


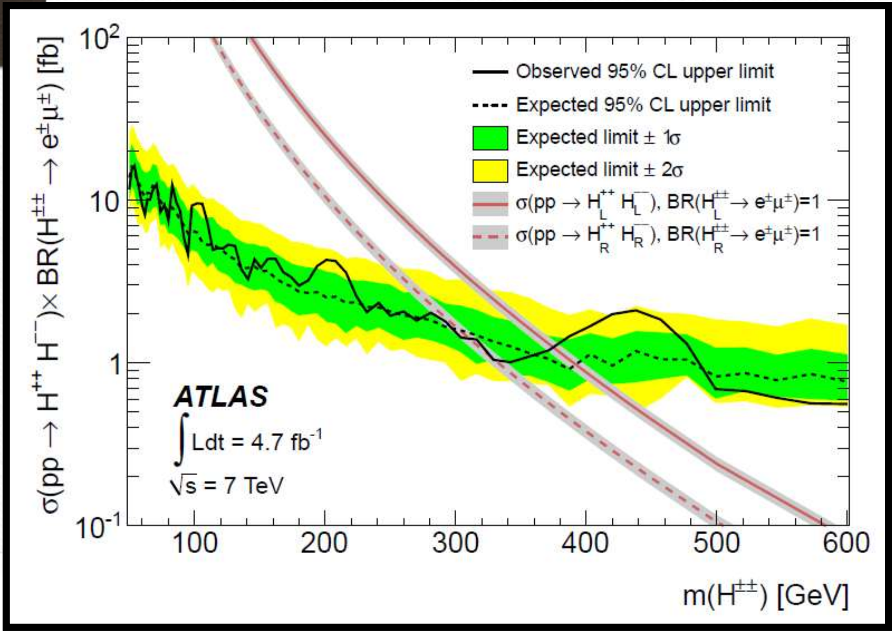
ATLAS
∫Ldt = 4.7 fb⁻¹
√s = 7 TeV
Data 2011
Non-prompt
Charge flips
Prompt
e±μ±
Leptons / 10 GeV
Leading lepton p_T [GeV]

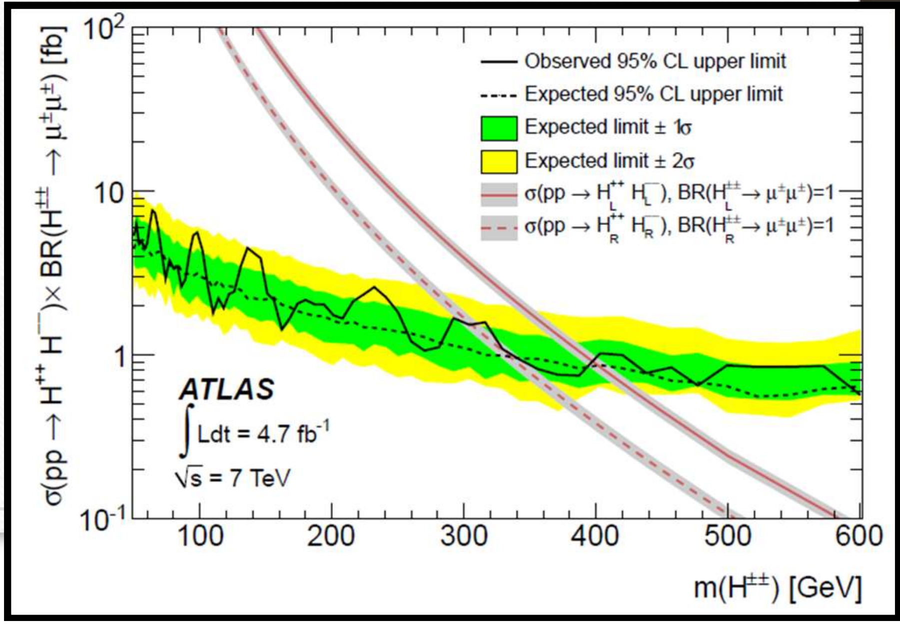
95% CL expected and observed upper limits of σ ant BR=100%

$$\sigma(pp \to H^{\pm\pm}H^{\mp\mp}) \times BR(H^{\pm\pm} \to l^{\pm}l'^{\pm}) = \frac{N^{rec}(l^{\pm}l'^{\pm})}{2 \times A \times \epsilon \times \mathcal{L}'}$$

$$0.6\, fb < \sigma(pp \to H^{\pm\pm}H^{\mp\mp}) < 25\, fb$$



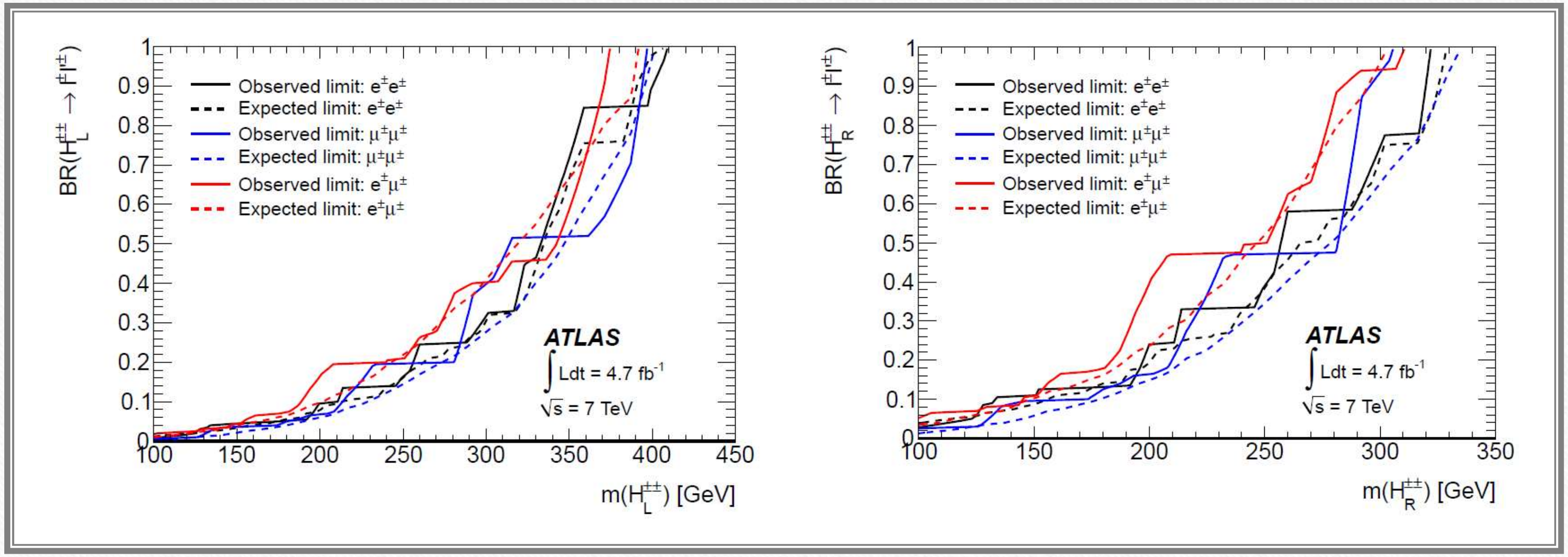




Lower mass limit at 95% CL

$BR(H_L^{\pm\pm} \to \ell^{\pm}\ell'^{\pm})$	95% CL lower limit on $m(H_L^{\pm\pm})$ [GeV]					
	$e^{\pm}e^{\pm}$		$\mu^{\pm}\mu^{\pm}$		$e^{\pm}\mu^{\pm}$	
	exp.	obs.	exp.	obs.	exp.	obs.
100%	407	409	401	398	392	375
33%	318	317	317	290	279	276
22%	274	258	282	282	250	253
11%	228	212	234	216	206	190

$BR(H_R^{\pm\pm} \to \ell^{\pm}\ell'^{\pm})$	95% CL lower limit on $m(H_R^{\pm\pm})$ [GeV]					
	$e^{\pm}e^{\pm}$		$\mu^{\pm}\mu^{\pm}$		$e^{\pm}\mu^{\pm}$	
	exp.	obs.	exp.	obs.	exp.	obs.
100%	329	322	335	306	303	310
33%	241	214	247	222	220	195
22%	203	199	223	212	194	187
11%	160	151	184	176	153	151



Mass limits as a function of the branching ratio

Conclusions

- No such peak was observed in a data sample in 2011

- Masses below 409 GeV, 398 GeV, and 375 GeV are excluded at 95% CL for $e^{\pm}e^{\pm}$, $\mu^{\pm}\mu^{\pm}$, and $e^{\pm}\mu^{\pm}$ final states, respectively

- The limits on $H_L^{\pm\pm}$ bosons also apply to the singlet in the Zee-Babu model

QUESTIONS & DOUBTS

THANK YOU FOR YOUR ATTENTION